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Fabrication and Testing of Reinforced Natural Fiber Composite

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***Abstract*— Glass fibers are the most useful reinforcement material in composites. There are different types of glass fibers are used for various applications such as construction industries, military applications, aviation, automobiles etc. The interest in using natural fibers such as different plant fibers and wood fibers as reinforcement in plastics has increased during last few years. Natural fibers can be used instead of glass fibers as reinforcement in some structural applications. Natural fibers have many advantages compared to glass fibers, for example they have low density, and they are recyclable and biodegradable. Additionally they are renewable raw materials and have relatively high strength and stiffness. Their low-density values allow producing composites that combine good mechanical properties with a low specific mass.**

The effect of ply orientation on mechanical properties of reinforced natural composites like sisal fiber, kuruthola fiber, and banana fiber, is tested. In which the fibers are heat treated for enhancing the strength by removing moisture. Samples of deferent orientation of sisal fiber, kuruthola fiber, and banana fiber reinforced composites were fabricated. In this experiment the composite material is prepared from weight ratio of resin to mat is 3:1, for every 1kg of mat 3kg of polyester resin is used and for 100ml of resin 10ml of accelerator is used and ten drops of methyl ethyl ketone peroxide is used as catalyst to improve the speed of the reaction.

Keywords- Component; Sisal fiber, Kuruthola fiber, Polyster resin, Methyl ethyl ketone peroxide.

I. INTRODUCTION

Fibers probably represent the most important class of reinforcement for composite materials, due to their ability to transfer strength to matrix materials and greatly influence the properties of composites. Many types of fibers are combined with metal, resin and ceramic matrices to form useful fiber reinforced composite materials. Fiber reinforced composites are produced from a wide range of constituents and have evoked a lot of interest among engineers concerned with various applications such as aerospace and automotive.

Currently, there is growing interest in the development of new materials, particularly renewable resources that facilitate utilization of natural materials. Natural fibers such as bamboo, jute, banana, abaca, coir and sisal belong to this category. Although natural fibers generally have poor mechanical properties compared with the synthetic fibers currently available, they have the advantages of low density, low cost and low energy demand during manufacture.

Natural fibers have been employed in various applications and have been used in the cordage industry for a long time. Natural fiber reinforced cement composite materials have also been made for low cost construction materials. Al-Qureshi (1997) presented the development and manufacture of automotive body skins of jute fabric reinforced composite, and hybrid composites made from jute/fiber glass composite panels. Sisal is a natural fiber (Scientific name is Agave sisalana) of Agavaceae (Agave) family yields a stiff fiber traditionally used in making twine and rope. Sisal is fully biodegradable and highly renewable resource of energy. Sisal fiber is exceptionally durable and a low maintenance with minimal wear and tear strength. Sisal fiber is produced by the way known as decortications, where leaves are compressed by a rotating wheel set with blunt knives, so that only fibers will remain.

Glass fiber is a typical synthetic inorganic fiber whose wide use as reinforcement in applications ranging from fishing rods to storage tanks and aircraft parts is well known. At present, the most important grades of glass are:

1. E-glass, named for its electrical properties. E-glass has low alkali content and is the most common glass fiber on the market, as well as being the most widely used in the construction industry. E-glass is now widely used with polyester and epoxy resins for fiber reinforced composites.
2. S-glass, a stronger and stiffer fiber than E-glass, was originally developed for military applications. It is not widely used outside the military and other related specialty industries (e.g. aviation, automotive) because of its higher cost.
3. R-glass, a civil version of the S-glass fiber, is used for high technology application.
4. C-glassis a special mixture used for chemical resistance, mainly against acid attack.

Hybrid fiber reinforced composites are attractive structural materials and their advancement is a relatively young and dynamic one. Hybrid fiber composites contain more than one class of fiber. Fiber hybridization presents new opportunities for tailoring the composite material to specific cost-effective applications and achieving properties that cannot be realized in one single class of fiber reinforced composites. In the development of hybrid fiber reinforced composite materials; one of the major problems that need to be addressed is reduction in cost of expensive composites with reinforcement by incorporating a proportion of cheaper fiber. The use of a low cost matrix material such as polyester, and the hybridization of natural fibers and synthetic fibers produce hybrid fiber reinforced composites with appreciable lightness and ease of fabrication of complicated shapes. The hybrid composites have significant economic advantages over wholly synthetic composite materials. Fiber-reinforced composite materials are being increasingly employed to manufacture structural components which are designed to be used successfully in dynamic environments under various temperatures in many diverse industries, such as the aerospace, transportation and sporting goods industries. As these engineering applications further diversify, the necessity for experimental data and analysis of the proposed design methodologies becomes more important. This is especially so when composite materials are subjected to dynamic mechanical loading under changing ambient conditions. When the temperature and moisture change, so does the dynamic mechanical behavior of the structural component fabricated by a composite material. The dynamic mechanical properties have a major influence on the response of the material and the structural integrity of the component.

II. STRUCTURE AND PROPERTIES OF FIBRES

Fibers are the major constituent in a fiber-reinforced composite material in terms of volume fraction and load-bearing capacity. In structural applications, fibers occupy large volume fractions in a composite laminate and share the major portion of the load on a composite structure. According to commercial and domestic use, fibers are broadly classified as natural fibers and synthetic (man-made) fibers.

2.1 Banana fiber

Banana plants are now found in most tropical regions. In Australia, they are extensively grown in Queensland and northern New South Wales. As indicated by Mickels (1990), the banana plant has a tree-like appearance and a trunk-like stalk, although h contains no woody material and can grow from 3.0 m to 9.0 m. The stalk, which ranges in diameter from 200 mm to 370 mm, consists of layers of overlapping leafstalk surrounding a hollow core. At the end of each stalk is a dark-green oblong leaf, measuring about 3600 mm by 600 mm. The stalk contains long multi-celled fibers extending length-wise through the pulpy tissues of long leaves or leaf-stems.

2.2 Sisal fiber

Sisal fibers are obtained from Agave Sisalana, a native of Mexico. The hardy plant grows well all year round in hot climate and arid regions which are often unsuitable for other crops. Sisal can be cultivated in most soil types except clay and has low tolerance to very moist and saline soil conditions. Husbandry is relatively simple as it is resilient to disease and its input requirement is low compared to other crops. Sisal can be harvested from 2 years after planting and its productive life can reach up to 12 years, producing from 180 to 240 leaves depending on location, altitude, level of rainfall and variety of plant.

2.3 Glass fiber

Glass fibers are probably the most common of all reinforcing fibers for polymeric matrix composites. The major type of glass fiber is E-glass, which is a borosilicate glass with a little alkali present in its composition. E-glass represents one of the lowest costs of all commercially available reinforcing synthetic fibers, which is the major reason for its widespread use in the fiber reinforced composites industry.

In general, the principal advantages of glass fibers include high tensile strength, high chemical resistance and good insulating characteristics. On the other hand, the disadvantages are low modulus compared to other high performance fibers such as carbon and kevlar fibers, relatively high specific gravity (among the commercial fibers), high cost (compared to natural fibers), sensitivity to abrasion with handling which frequently decreases tensile strength, low fatigue resistance and high hardness.

III. FIBER REINFORCED COMPOSITE MATERIALS

- Fiber-reinforced composites: composed of continuous or chopped fibers.
- Particulate composites: composed of particles dispersed in a matrix. The particles are distinguished from the filamentary type, and may be round, square or even triangular, but the side dimensions are approximately equal. Ceramic and metal composites that are made up of particles with one phase dispersed in the other phase are known as particle reinforced composites. The material properties are dependent on not only the constituent, but also the interfacial properties and geometric shapes of the array.
- Flake composites: composed of flat flakes, or platelets. Flakes can be more tightlypacked than other type composites. Metal flakes touching each other in a polymer matrix can conduct heat or electricity. In some cases, flakes are easier and less expensive to produce than fibers. However, flakes may be difficult to line up parallel to one another in a matrix resulting in uneven strength and other properties. The disadvantages of flake composites are the quality control of the sizes, shape and distribution flaws in the final product. Aluminum flake composites are used in metallic automobile paints to provide decorative color effects and various degrees of transparency. Glass flakes are applied to printed circuit boards for computers (Agarwaland Broutman 1980).

- Filled composites: filler materials are added to a plastic matrix to replace part of the matrix or to add to or to change the overall properties of the composite. In some cases, the fillers actually offer an increased strength of the composite, a reduction in weight and the quantity of plastic used. However, fillers also have disadvantages, and may limit the method of fabrication or inhibit curing of certain resins.
- Continuous fiber composites: The fiber may be arranged either in a unidirectional orientation or in a multi axial orientation. A laminate formed by continuous fibers has the highest strength and modulus in the longitudinal direction of the fibers, but in the transverse direction, its strength and modulus are relatively low.
- Woven fiber composites: The delamination or separation of the laminates is still a major problem due to the fibers not being as straight as in the continuous fiber laminate. Hence, strength and stiffness are sacrificed. However, the woven fiber composites are not relevant to delamination because they do not have dependent laminae.
- Chopped fiber composites: With random orientation of fibers, it is possible to obtain nearly uniform mechanical and physical properties in all direction. Chopped fiber composites are used extensively in high-volume applications such as building materials, because of low manufacturing cost.
- Hybrid fiber composites: Mixed chopped and continuous fibers, or mixed differentfiber types such as glass/carbon fiber and natural/synthetic as well. Hybrid fiber composites provide the chance of achieving a balance of mechanical properties and cost.

3.1 Hybrid Fiber Composites

Hybrid fiber composites contain two or more kinds of fibers, which are incorporated into a single matrix. Although individual types of fibers may contribute some desirable property, the particular interest in composite material systems lies in optimizing the different contributions from different types of fibers, whilst at the same time, paying attention to optimizing cost effectiveness. Hybrid fiber composites therefore provide researchers an opportunity for tailoring composites to achieve desired properties (Kretsis 1987).

According to the arrangements of fibers and layers, hybrid fiber composites can be generally classified into the following types (Chou 1992):

• Intermingled: Different fiber materials are mixed together and passed through a matrix simultaneously,

• Interlaminated: Each separate laminate containing just one type of fiber. The laminae are bonded together in a matrix,

• Interwoven: Composed of fabric reinforcements where each fabric contains more than one type of fiber.

IV. FABRICATION AND TESTING

4.1 Fabrication process

Thermosetting resin systems, by chemical reaction become hard when cured and further heating does not soften them, the hardening is irreversible. During curing they undergo a chemical change or reaction called polymerization, the linking of monomers or pre-polymers to form network polymers. This reaction is accomplished in the presence of curing agents usually selected to give a desired combination of time and temperature to complete the reaction suitable for a particular product. Further the curing can be staged so that impregnation or composite forming can be accomplished.

Fabrication process for thermosetting resin matrix composites can be broadly classified as wet forming process and processes using pre-mixes. The wet process includes hand layup, filament winding, and bag molding. In the processes using pre-mixes compounding is separated from layup or moulding. Compounding is done to make such pre-mixes as bulk moulding compounds, sheet moulding compounds and prepares. The matrix material in some of the premixes is thickened so that it is tack free or slightly tacky, does not flow and can be handled easily. Thickening is achieved by the use of a thickening agent and by advancing the cure of the resin. In the latter case, they must be stored and transported at low temperatures. High fiber volume fractions can be achieved with uniform fiber distribution.

In case of kuruthola sisal, and banana fibers these are cut in uniform width and thickness then the fibers are heat treated for enhancing the strength by removing moisture. After removing moister content in the fibers continuous mat is to be produced.

4.2 Resin mixture preparation

Figure 4.1 Preparation of Resin mixtures

5.2.1 Constituents of composite material

- Accelerator = Cobalt
- Catalyst = Methyl Ethyl ketone peroxide
- Weight of the resin= 3kg of resin for every 1kg of mat.
- Quantity of the catalyst = 10 drops of Methyl Ethyl Ketone Peroxide.
- Quantity of the accelerator =10ml of cobalt for 100 ml of resin.

The constituents of polyester composite material are the woven mat, polyester resin, Cobalt which is used as accelerator and Methyl Ethyl Ketone Peroxide which is the catalyst. The ratio of weight of resin to weight of mat is 3:1.

For every 1kg of mat, 3kg of polyester resin is used and for 100ml of resin 10ml of accelerator is used. Ten drops of Methyl Ethyl Ketone Peroxide is used as the catalyst. The catalyst improves the speed of the reaction and the accelerator will speed up the solidification of the composite material. Wax (petroleum jelly) is applied on the mold surface for easy removal of the composite material and Acetone is used for washing the roller brush used for applying the polyester resin. The polyester resin sticks on the roller brush and for further application of the liquid resin, the stacked polyester resin is to be removed. So acetone is applied on the roller brush for removing the stacked polyester resin.

4.3 Hand layup technique

Hand layup technique is the oldest, simplest, and the most commonly used method for the manufacture of both small and large reinforced products. Fiber reinforcements and resins are placed manually against the mold surface. Thickness is controlled by the layers of materials placed against the mold. A chemical reaction initiated in the resin by a catalytic agent causes hardening to a finished part. Hand laying techniques are best used in applications where production volume is low and other forms of production would be prohibitive because of costs or size requirements. Typical applications include boat and boat hulls, ducts, pools, tanks and corrugated and flat sheets. The following operations are involved in a typical hand layup process.

4.4 Mold preparation

This is one of the most important functions. If it is done well the molding will look good and separate from the mold easily. After the desired finish has been attained, several coats of paste wax are applied for the purpose of mold release.

4.5 Hand layup

After properly preparing the mold and coating it the next step in the process is material preparation. In hand layup the fiber glass is applied in the form of chopped strand mat or woven roving. Premeasured resin and catalyst (hardener) are then thoroughly mixed together. The resin mixture can be applied to the glass either outside or on the mold. To ensure complete air removal and wet out, serrated rollers are used to compact the material against the mold to remove any entrapped air. The work must be done quickly enough to complete the job before the resin starts to cure. Various curing times can be achieved by altering the amount of catalyst employed. At the end load is applied from top to press out any excessive resin along with trapped air.

Step 1: The place is covered with a release sheet. And apply wax on the sheet; it will help the final product to be removed from the mold very easily.

Figure 4.2 Release sheet placed in the mold

Step 2: Resin mixture is poured and is spread uniformly over the sheet with the help of roller

Figure 4.3Applying resin

Step3: the woven glass fiber mat is placed carefully on the resin which is previously applied.

Figure 4.4placing woven mat

Step 4: The resin is again applied on the layer in same manner as in the step2. It is then spread out evenly with the help of roller. A little pressure is applied so as to remove any trapped air.

Figure 4.5 Apply resin into roving

Step5: Place and role the layer of chopped strand mat

Figure 4.6 Place chopped strand mat

Step6: The resin is applied with the help of a brush in the case of chopped strand mat

Figure 4.7 Apply the resin to chopped strand mat

Same procedure is repeated in the case of natural fibers like sisal fibers, kuruthola fibers, and banana fibers.

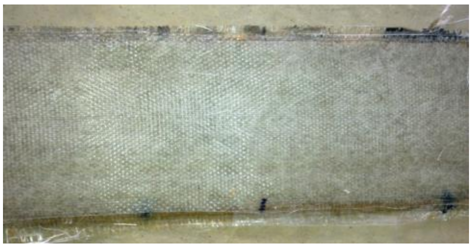

Fig 5.8 0/90 Ply orientation of glass fiber

1 RESULTS AND DISCUSSION

5.1 Tension Test Results

TABLE 5.1 TENSILE TEST OF GLASS FIBER REINFORCED COMPOSITE MATERIAL

Specimen orientation	Number of trails	Tensile Strength (MPa)	Breaking Load (N)	% Elongation
	T1	64.52	1675.23	1.32
$0/45^0$	T2	71.68	1824.65	1.86
	T3	73.46	1918.39	2.14
	Average	69.88	1806.09	1.77
	T1	95.35	2746.17	3.13
	T2	96.82	3114.28	3.64
$0/90^0$	T3	95.64	2965.74	3.21
	Average	95.63	2942.06	3.32

TABLE 5.2 TENSILE TEST OF SISAL FIBER REINFORCED COMPOSITE MATERIAL

Specimen orientation	Number of trails	Tensile Strength (MPa)	Breaking Load (N)	% Elongation
	T1	19.81	2462.12	1.82
$0/45^0$	T2	20.24	2484.53	2.12
	T3	20.56	2497.73	2.56
	Average	20.20	2481.46	2.16
	T1	40.86	4857.12	3.86
	T2	39.74	4852.54	4.13
$0/90^0$	T3	38.92	4846.88	4.24
	Average	39.84	4852.18	4.07

TABLE 5.3 TENSILE TEST OF KURUTHOLA FIBER REINFORCED COMPOSITE MATERIAL

Specimen orientation	Number of trails	Tensile Strength (MPa)	Breaking Load (N)	% Elongation
	T1	6.53	436.25	0.06
	T2	6.86	456.53	0.06
$0/45^0$	T3	6.12	403.49	0.05
	Average	6.50	432.09	0.056
	T1	8.54	510.24	0.12
	T2	9.21	632.86	0.14
$0/90^0$	T3	8.76	532.14	0.12
	Average	8.83	558.41	0.126

TABLE 5.4 TENSILE TEST OF BANANA FIBER REINFORCED COMPOSITE MATERIAL

Specimen orientation	Number of trails	Tensile Strength (MPa)	Breaking Load (N)	% Elongation
	T1	8.16	514.53	0.12
	T2	7.62	481.66	0.10
$0/45^0$	T3	7.86	496.83	0.11
	Average	7.88	497.67	0.11
	T1	11.12	735.53	0.18
	T2	10.86	718.33	0.17
$0/90^0$	T3	10.97	712.38	0.17
	Average	10.98	722.08	0.173

Tensile test were done in universal testing machine for the glass fiber, sisal fiber, kuruthola fiber, and banana fiber reinforced polyester resin composite. The tensile test was done to get the properties of the composite material.

The table 5.1 shows the results of tensile test conducted on for the glass fiber composite for 0/90 orientation and 45^0 orientation. The table 5.2 shows the results of tensile test conducted on for the sisal fiber composite for 0/90 orientation and 45^0 orientation. The table 5.3 shows the results of tensile test conducted on for the kuruthola fiber composite for 0/90 orientation and 45^0 orientation. The table 5.4 shows the results of tensile test conducted on for the banana fiber composite for 0/90 orientation and 45^0 orientation. The elongation of the fiber for the corresponding load has been noted.

The breaking load of Glass fiber reinforced polyester composite for 0/90 orientation is 2942.06 N/mm2 and the breaking load of sisal fiber reinforced polyester composite for 0/90 orientation is 4852.18N.As compared to sisal fiber reinforced polyester composite The glass fiber reinforced polyester composite material is brittle and suddenly ruptures at the breaking load.

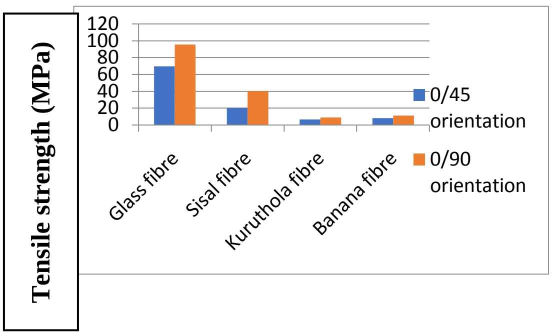

Figure 5.1 Tensile strength of reinforced composite materials

5.2 Flexural Test Results

TABLE 5.5 FLEXURAL TEST OF GLASS FIBER REINFORCED COMPOSITE MATERIAL

Specimen orientation	Number of trails	Flexural Strength (MPa)	Flexural Load (N)
	T1	176.74	217.62
	T2	178.52	220.25
$0/45^0$	T3	181.45	219.84
	Average	178.90	219.23
	T1	198.24	254.38
	T2	202.69	274.21
$0/90^0$	T3	201.42	268.63
	Average	200.78	265.74

TABLE 5.6 FLEXURAL TEST OF SISAL FIBER REINFORCED COMPOSITE MATERIAL

Specimen orientation	Number of trails	Flexural Strength (MPa)	Flexural Load (N)
	T1	52.26	201.12
	T2	66.52	186.44
$0/45^0$	T3	62.38	203.68
	Average	60.38	197.08
	T1	146.26	457.25
	T2	172.62	465.24
$0/90^0$	T3	158.84	452.86
	Average	159.24	458.45

TABLE 5.7 FLEXURAL TEST OF KURUTHOLA FIBER REINFORCED COMPOSITE MATERIAL

Specimen orientation	Number of trails	Flexural Strength (MPa)	Flexural Load (N)
	T1	65.24	311.25
	T2	64.95	298.69
$0/45^0$	T3	67.25	327.62
	Average	65.81	312.52
	T1	158.56	475.69
	T2	155.96	469.87
$0/90^0$	T3	157.24	473.26
	Average	157.25	472.94

TABLE 5.8 FLEXURAL TEST OF BANANA FIBER REINFORCED COMPOSITE MATERIAL

Specimen orientation	Number of trails	Flexural Strength (MPa)	Flexural Load (N)
	T1	72.34	320.56
	T2	76.85	346.58
$0/45^0$	T3	73.25	331.85
	Average	74.15	332.99
	T1	196.38	578.75
	T2	191.25	569.64
$0/90^0$	T3	189.94	562.35
	Average	192.52	570.24

The table 5.5 shows the results of flexural test conducted on for the glass fiber composite for 0/90 orientation and 45^0 orientation. The table 5.6 shows the results of flexural test conducted on the sisal fiber composite for 0/90 orientation and 45^0 orientation. The table 5.7 shows the results of flexural test conducted on kuruthola fiber composite for 0/90 orientation and 45^0 orientation. The table 5.8 shows the results flexural test conducted on the banana fiber composite for 0/90 orientation and 45^0 orientation.

The flexural load of Glass fiber reinforced polyester composite for 0/90 orientation is low (265.74 N) as compared to natural fiber polymer composite like sisal fiber reinforced polyester (458.45 N), kuruhola fiber reinforced polyester (472.94 N), and banana fiber reinforced polyester (570.24 N).As compared to sisal fiber reinforced polyester composite the glass fiber reinforced polyester composite material is brittle and suddenly ruptures at the flexural load.

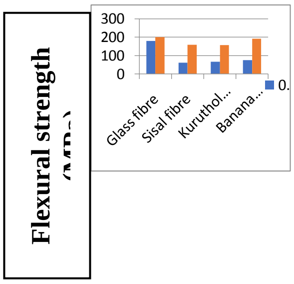

Figure 5.2 Flexural strength of reinforced composite materials

5.3 Hardness test results

TABLE 5.9 HARDNESS TESTS OF GLASS, SISAL, KURUTHOLA, BANANA FIBER REINFORCED COMPOSITE MATERIAL

Polymer matrix composite material	Trail 1 (Shore A)	Trail 2 (Shore A)	Trail 3 (Shore A)	Average (Shore A)
Glass fiber	88	84	89	87
Sisal fiber	76	70	72	72.67
Kuruthola fiber	83	82	80	81.67
Banana fiber	54	62	59	58.33

The table 5.9 shows the results of hardness test conducted on for the glass, sisal, kuruthola, and banana fiber composite for 0/90 orientation and 45^0 orientation in which the glass fiber polymer composite is more harder than other natural fibers.

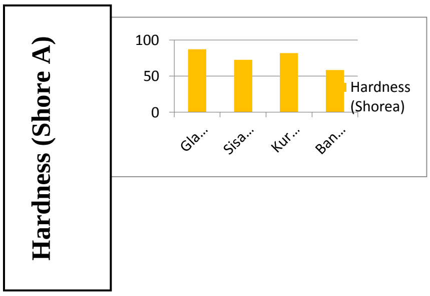

Figure 5.3 Hardness strength of reinforced composite materials

5.4 Density Test Results

TABLE 5.10 DENSITY TESTS OF GLASS, SISAL, KURUTHOLA, BANANA FIBER REINFORCED COMPOSITE MATERIAL

Polymer matrix composite material	Relative Density	Density (Kg/m^3)
Glass fiber	1.476	1476
Sisal fiber	1.162	1162
Kuruthola fiber	1.115	1115
Banana fiber	1.008	1008

The table 5.10 shows the results of density test conducted on for the glass, sisal, kuruthola, and banana fiber composite for 0/90 orientation and 45^0 orientation in which the glass fiber polymer composite have high density than other natural fibers.

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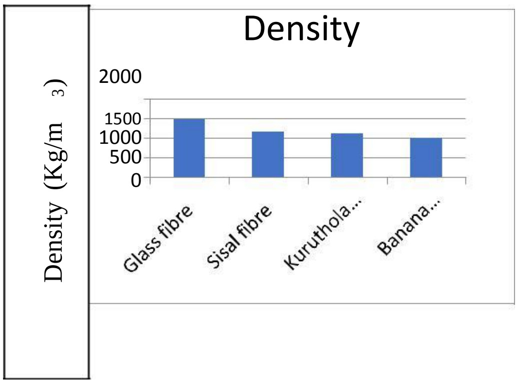

Figure 6.4 Density of reinforced composite materials

5.5 Charpy Impact Test Results

TABLE 6.11 IMPACT TESTS OF GLASS, SISAL, KURUTHOLA, BANANA FIBER REINFORCED COMPOSITE MATERIAL

Polymer matrix composite material	Impact energy in scale (Joule)
Glass fiber	18
Sisal fiber	10
Kuruthola fiber	6
Banana fiber	5

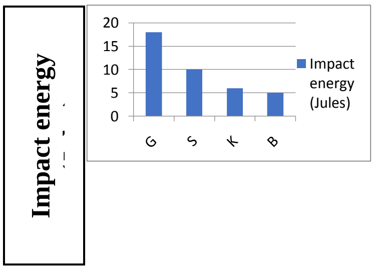

Figure 5.5 Impact strength of reinforced composite materials

The table 6.11 shows the results of charpy impact test conducted for the glass, sisal, kuruthola, and banana fiber composite for 0/90 orientation and 45^0 orientation in which the glass fiber polymer composite have high impact strength than other natural fibers.

VI. CONCLUSION

A polymer matrix composite contains various natural fibers and glass fiber as the reinforcement phase is fabricated. In this work two types of orientations were used, ASTM standards were used for testing the part might require 45^0 to react to shear loads and 90^0 to react to side loads. The main advantage of glass fibers are they have good mechanical properties while the main disadvantage is difficulty in recycling. The natural fiber composites like sisal fiber, banana fiber, and kuruthola fiber composites reach the mechanical properties of glass fiber composites and also in which 90^{0}orientation (unit directional) have good mechanical properties than 45^{0}orientation. Due to the low density, bio degradability, and high specific properties natural fiber composite have very good future applications in modern industry.

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